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FIELD TEST EVALUATION OF THE CTAS CONFLICT PREDICTION AND TRIAL PLANNING CAPABILITY

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Abstract

The conflict prediction and resolution capability resident in the Center/TRACON Automation System (CTAS) has been enhanced and field tested. All-track processing (overflights, arrivals, departures), conflict probability estimation, and interactive trial planning, were incorporated into the Conflict Prediction and Trial Planning (CPTP) tool for field test evaluation. The objective of the work was to field test CPTP under operational air traffic control conditions and to measure benefits of CPTP capability to air traffic controllers and airspace users. The system was tested on the operational floor at the Denver Air Route Traffic Control Center in September 1997. It was found that controllers using CPTP-aiding resolved many conflicts by issuing a direct-route clearance to one of the aircraft. A direct route often resolved a conflict well before it became tactical, gave the aircraft a short-cut, and required one less controller clearance. The potential for a three-fold increase in direct routing was noted with CPTP-aiding over baseline operations with no aiding. The data show better than a two-fold increase in the number of direct-route clearances actually issued to aircraft when controllers were using the CPTP system. The ability of CPTP to confirm that a trial trajectory resolves the conflict without creating any other conflicts was consistently identified by the controllers as one of its most powerful features.

Introduction

NASA Ames Research Center is developing decision support tools for air traffic controllers to improve the efficiency and capacity of the National Airspace System. The goal is to provide technology and procedures that result in the highest possible level of user preferred routing whenever possible with efficient traffic management when necessary. The work is being conducted under the NASA Advanced Air Transportation Technology Program in cooperation with the Federal Aviation Administration (FAA) through the Inter-Agency Integrated Product Team. The trajectory analysis methodology and software developed for the Center/TRACON Automation System (CTAS) is being used as a baseline for development.

CTAS is a set of decision support tools designed to help air traffic controllers increase efficiency and capacity of arrival traffic flow near congested airports. The Traffic Management Advisor (TMA) creates sequences and schedules for arrival aircraft to make efficient use of runway capacity. The Descent Advisor (DA) computes descent profile advisories for fuel-efficient, conflict-free transition of arrival aircraft from enroute/cruise flight down to the terminal area. The Final Approach Spacing Tool (FAST) develops advisories to help TRACON controllers guide aircraft from entry into the terminal area to touchdown at the runway. CTAS tools are currently at various stages of development and deployment at FAA air traffic control facilities. CTAS Build 1 includes TMA as a daily-use prototype at the Atlanta, Denver, Los Angeles and Miami Air Route Traffic Control Centers (ARTCC) and TRACON facilities. CTAS Build 2 includes TMA as a daily-use prototype at the Ft. Worth Center and Dallas/Ft. Worth TRACON, and FAST, being introduced to daily operation at the TRACON.

The CTAS Conflict Prediction and Trial Planning (CPTP) capability is an extension of conflict prediction and resolution functions originally developed for the DA[1,2]. CPTP uses the trajectory-analysis methodology common to all CTAS tools. It has been expanded to include all trajectory types (arrivals, departures, overflights). The conflict prediction algorithm[3] has been improved, and conflict probability estimation[4,5] incorporated. A new user interface allows a controller

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to quickly develop and check a trial-plan ("what if") trajectory for conflict resolution through mouse point-and-click on flight data block fields[6]. A CPTP User's Guide was written for training and technology transfer[7]. A quantitative analysis of CTAS conflict prediction performance using actual air traffic data has been performed[8].

Conflict prediction and resolution technology is also being developed by the MITRE Center for Advanced Aviation System Development. The User Request Evaluation Tool (URET)[9] provides conflict prediction and trial planning functions for Center controllers, and has been field tested at the Indianapolis and Memphis Centers. It is scheduled for FAA installation at several enroute Centers. For enhanced capability in the longer term, NASA research focuses on the integration of conflict prediction and resolution capability with TMA and DA to enhance user-preferred trajectories in the extended terminal area.

This paper describes a field test evaluation of CPTP capability at the Denver ARTCC in September 1997. It begins with a summary of controller simulation and shadow control evaluations that contributed significantly to the system that was field tested. An overview of CPTP functionality is next, followed by a description of field test operations and results. Finally, the paper addresses some problems encountered during the test and post-test analysis, and closes with a list of conclusions and recommendations.

Simulation and Shadow Control Evaluations

Controller participation in the development of any decision support tool for air traffic controllers is the only way to ensure usability and controller acceptance under operational conditions. Fourteen days of controller–in-the-loop simulations were conducted over seven months prior to the field test. The Pseudo Aircraft Simulation (PAS) system was used to generate traffic scenario data for CTAS. The simulations included CTAS Planview Graphical User Interface (PGUI) workstation monitors (20 in) configured for R- and D-Side controller positions. Traffic with flight data blocks were displayed on the R-Side monitor, while CPTP was running on the D-Side monitor. Hand-offs and frequency changes were simulated using PAS, (flight strips were not included). Fourteen air traffic controllers representing nine FAA Centers participated in the simulations. Controller input during these evaluations had a significant effect on the CPTP functionality that was field tested.

Five controllers from Denver, Oakland, and Atlanta Centers participated in 6 days of simulation during February-March, 1997. Controller feedback collected in debriefing sessions suggested that the basic conflict prediction functionality was well accepted, but the user interface needed significant improvement. The interface functionality for trial planning was found to be especially difficult for the controllers to use effectively.

The positive response by U.S. air traffic controllers to the Eurocontrol Operational Display and Input Development (ODID) interface resulted in a decision to incorporate some of the ODID design concepts into the CPTP interface. An ODID-like design for point-and-click trial planning accessible through fields on the aircraft flight data block was implemented as a replacement to trial planning with keyboard entries. The new user interface allows the controller to enter trial plan conflict resolution information by pointing and clicking with the computer mouse on data block fields and pop-up menu lists. The result is an interface that allows the controller to be “eyes-up” on the traffic display with hands off the keyboard. A design review of the new interface was conducted in June 1997 with two controllers, representing Boston and Atlanta Centers, who were experienced in the use of the ODID interface[6].

Three days of simulation were conducted in July 1997. The objective was to involve controllers from several Centers who had not yet been involved in the development of CPTP or other CTAS tools. The simulation was developed with the help of two controllers from Ft. Worth and Oakland Centers. Four controllers, one each from Chicago, Houston, Los Angeles, and New York Centers, participated in the simulation evaluation. Controller feedback on CPTP design and use was positive and all four controllers felt its capability could benefit their respective facilities. Three controllers from Ft. Worth Center participated in a three-day simulation evaluation in August 1997. Their feedback concurred with the earlier evaluations.

CPTP Functional Summary

In order to obtain the best possible 4-D trajectory prediction, CTAS uses radar track measurements and flight plans from the ARTCC's Host computer, along with wind predictions from the National Centers for Environmental Prediction's Rapid Update Cycle (RUC) model, and aircraft performance models like those used in aircraft Flight Management Systems[10]. CTAS trajectory predictions for all aircraft in the Center airspace are updated with radar track data approximately every 12 seconds, with flight plans and amendments as aircraft enter the Center or change their route of flight or cleared altitude, and with wind predictions based on 3-hour forecasts from the 60 km RUC model[11].

Conflict prediction is based on a comparison of all trajectory pairs approximately every 6 seconds. The conflict prediction algorithm runs independently of the trajectory prediction algorithm and always uses the most recently calculated trajectories. Conflict display criteria such as separation and time horizon are adjustable through a setup panel accessible through the user interface. The separation criteria used throughout the field test were 10 nmi and 2000 ft. for aircraft above 29,000 ft., and 10 nmi and 1000 ft. for aircraft below 29,000 ft. The time horizon for conflict analysis was 0-20 min. A sector filter determines which conflicts to display at any given sector position. The filter was nominally configured to display all conflicts predicted to occur within the test sector(s) plus any conflicts predicted to occur outside the test sector involving at least one aircraft currently inside the test sector.

Operation of the CPTP is best illustrated by a simple traffic example. Figure 1 shows conflict prediction information on a planview traffic display. The Conflict Prediction list contains aircraft pairs currently predicted to violate user-defined separation criteria. The pairs are ordered according to time-to-first-loss of separation (TIME). The minimum predicted vertical (FL) and horizontal (NM) separations are also shown in the list. Flight data blocks are automatically displayed for aircraft predicted in conflict. The fourth line of the data block shows the conflict aircraft call sign in red (bold in figures). The conflict list is updated every 6 seconds.

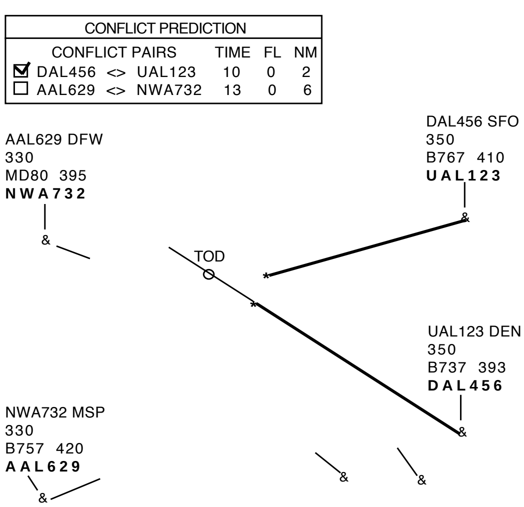

Fig. 1 Conflict prediction display.

The controller may select a conflict pair for closer analysis by point-and-click on the call sign in the flight data block of either conflicting aircraft, or by clicking on the box next to the aircraft pair in the conflict list. The resulting display shows trajectory predictions in red (bold in figures) for both aircraft from current position to predicted first loss of separation. Selecting a pair also forces the pair to remain in the list even when predicted separation no longer violates the separation criteria. If the conflict pair includes an arrival or departure aircraft, predicted top-of-descent (TOD) or top-of-climb points are shown. Since descent trajectories are computed for fuel efficiency, the TOD is based on a near-idle thrust descent from cruise altitude to meter fix.

The trial planner is an interactive tool which allows the controller to determine the effect of a route change by vector, altitude, or speed (or combination). A trial plan is initiated by point-and-click on certain data block fields. A trial-plan trajectory is computed separately from the active trajectory and is checked for conflict against all other trajectories. Conflict information for the plan is displayed in a Trial Conflicts list which is updated approximately every second to give the controller rapid feedback on the trial-plan conflict status. This list shows separation data for the conflict aircraft and any aircraft predicted to be in conflict with the trial trajectory. The controller adjusts the trial plan while monitoring the Trial Conflict list. When the list indicates adequate separation and confirms that the trial plan creates no other conflicts, the controller may issue a clearance to the aircraft and "accept" the trial plan. Acceptance of the trial plan converts the trial-plan trajectory to an active trajectory, which should then be conflict-free.

A direct route or vector trial plan is initiated by clicking the destination airport field in the flight data block. For a vector trial plan, the following information is displayed: a default trial trajectory is shown in yellow (dashed in figures), an entry in the Trial Conflict list, a capture waypoint menu, wind-corrected magnetic heading to the next waypoint, and the estimated time to the next waypoint. The trial trajectory is defined as the route which starts at the current aircraft position, passes through any auxiliary waypoints (explained later) and returns to the flight plan route at the capture waypoint. A capture waypoint menu contains all 3 and 5 letter waypoints along the route of flight from current position to the destination airport. This menu allows the controller to quickly view and select a capture waypoint along the route of flight without having to bring up a separate flight plan menu and then type in a waypoint name.

As shown in Fig. 2, the user initiated a vector trial plan for DAL456 by clicking on the destination airport field (SFO) and then clicking waypoint OCS in the capture waypoint menu (not shown). In this case, "direct to OCS" did not resolve the conflict, so the user clicked at a point along the nominal trial trajectory to create an auxiliary (aux) waypoint, and then dragged it to the position shown by the arrow. As the user drags the waypoint, the trial route and the trial conflict list are continually updated (every sec). This gives the controller rapid feedback on the conflict status and quickly indicates if other conflicts have been created. The Trial Conflict list shows that the conflict is resolved with 11 nmi predicted separation. The "TP/R" in the fifth line of the data block indicates that a conflict-free trial plan is pending. When a trial plan is pending, clearance information is displayed next to the aircraft symbol (&) showing magnetic heading (240) to the next waypoint (A1, the aux waypoint), and the predicted time to that waypoint (8:30). The controller could issue a clearance as: "Delta 456 turn left heading 240, expect direct OCS in 8 and one-half min".

Under current ATC operations, when a controller clears an aircraft direct to a downstream fix (waypoint) it is not uncommon for the fix to be outside of the Center boundary. Early in the field test planning the Denver Center test controllers suggested that it would be desirable to have a selected set of outside-Center fixes available for inclusion in the capture waypoint menu. This would allow the controller to quickly check direct routes to fixes outside the Center boundary. However, the data base used for adapting CTAS to Denver Center (or any Center) typically includes only fixes that are immediately outside the Center boundary. The Denver Center controllers provided a list of 35 additional outside-Center fixes to add to the CTAS Center adaptation data base. This enabled the route-analysis algorithm to build a route as far beyond the Center boundary as the additional fixes would allow, and made these fixes available for display in the capture waypoint menu in the trial-planning function.

The user may accept or reject a trial plan at any time by clicking the "TP" in the fifth line of the flight data block and then clicking accept or reject which appear in a small box next to the data block (not shown). Acceptance of a trial plan converts the trial plan route to an active route and turns off the trial-plan display and the Trial Conflict list. If the trial-plan route is conflict free (as would normally be the case for an accepted trial plan), the conflict pair would also be eliminated from the Conflict Prediction list. Acceptance of the trial plan

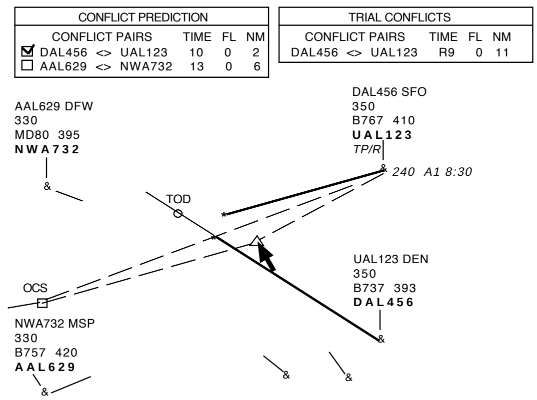

Fig. 2 A vector trial plan that resolves a conflict.

usually follows a clearance to the aircraft or any time the controller has confirmed that the aircraft is flying the trial plan route.

The user interface provides a clear indication to the controller if a trial plan creates another conflict. As shown in Fig. 3, a left turn to heading 230 for DAL456 resolves the conflict with UAL123 with 15 nmi separation, but creates another conflict with UPS215. In this case the controller simply drags the aux waypoint back to the trial route shown in Fig. 2 to effect the resolution. For most conflict situations a trained controller completes the process illustrated in Figs. 1-3 in less than 10 sec.

Altitude and speed changes are trial planned by clicking the respective altitude and speed fields in the flight data block. To trial plan altitude for DAL456 in Fig. 2, the user would click the "350" field to bring up an altitude menu. The user then clicks the desired trial altitude. CTAS builds a climb or descent trajectory to the selected altitude which is then probed against all other

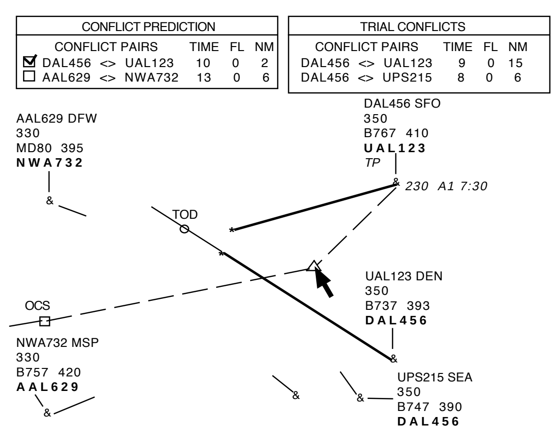

Fig. 3 A trial plan that creates a new conflict.

aircraft trajectories. A speed trial plan would be initiated by clicking on the “410” field. Reference 7 gives a complete description of the CPTP user interface.

Field Test Operations and Results

Field test evaluation of decision support technology under operational conditions requires close coordination with the FAA. Test objectives were: 1) test the CPTP capability under operational conditions with arrival, departure, and overflight traffic, 2) measure benefits of the technology for air traffic controllers and airspace users, 3) determine how CPTP technology may increase user-preferred routing. Denver Center was chosen because of previous experience with CTAS field testing, and the access to live all-track, all-flight-plan data from Denver Center’s Host computer. The September 1997 time frame was coordinated with the FAA about 9 months prior to the test and NASA and FAA Denver Center personnel worked together to develop specific test plans and procedures. A detailed test plan[12] was initially presented to Denver Center facility and FAA Headquarters personnel for review on June 3, 1997.

The CPTP field test system architecture is illustrated in Fig 4. All radar track and flight plan messages from the Host computer were sent to CTAS from a one-way Host software patch, through a 9600 baud serial interface device called a PAMRI-Emulator (PE). The CTAS/CPTP software architecture includes Host data acquisition (Radar), weather data acquisition (Wx), Communications Manager (CM), Route Analysis and Trajectory Synthesis (RA/TS), Conflict Prediction (PFS_C), and Planview Graphical User Interface (PGUI) processes which run on a networked set of Unix workstations. Trajectory predictions for all aircraft were divided among 4 RA/TS processors. CTAS software is written in C and C++.

A dedicated CPTP system was installed in the Denver Center CTAS office area in March 1997. This early installation facilitated controller participation in tool development, served as a prototype for the system that would be tested on the operational floor in September, and provided a system for test controller training. Controllers were trained by personnel from the Denver Center CTAS office with training materials provided by NASA. Training consisted of 2-hour sessions in which test controllers operated the CPTP tool in shadow mode with live traffic. Initial training was conducted one month prior to the test after which the controllers had the opportunity to use the system in the CTAS office area. A “rehearsal” Field Test was conducted the week of August 11, 1997 to validate the hardware

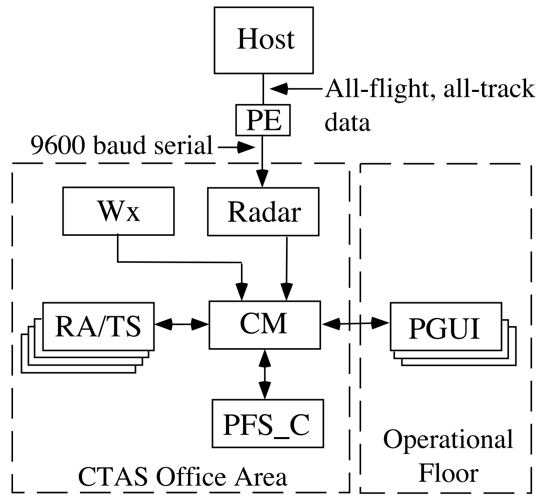

Fig. 4 CTAS/CPTP field test architecture.

configuration, a pre-release version of the software, and the planned test procedure.

The CPTP system was tested on the operational floor at Denver Center from September 8 - September 25, 1997. High altitude sectors 16 and 17 from Area 2, and sector 28 from Area 3 were chosen for the test. Sector 16 is an arrival/departure sector for Denver International Airport and sectors 17 and 28 contain a mix of arrival, departure, and overflight traffic. The tool was operated by full-performance level controllers who normally work the sectors chosen for the test. Testing was conducted during three 2-hour test periods per day, representative of light (12-2pm), medium (3-5 pm) and heavy (9-11am) traffic periods. Test controllers participated on a volunteer basis, but were relieved of their regular duties during field test operations. Sectors were selected from two different Areas to minimize the impact on staffing in any single area.

The Field Test was performed in two phases. During Phase I (week 1), the test controller worked the CPTP tool in “shadow” mode, i.e., without communication with the sector controller, in order to compare conflict prediction and resolution with and without the aid of the tool. During Phase II (weeks 2 and 3), each test controller sat next to the D-side controller position and used the CPTP tool to provide decision support directly to the sector controller. Table 1 shows the distribution of flight types for conflict pairs within Denver Center airspace in both Phase I and Phase II of the field test. Arrivals and departures are to and from airports within the Center, including Denver International Airport.

Table 1 Trial-plan Flight Types

Type	Phase I	Phase II
OV-OV	27	68
OV-AR	28	46
OV-DP	17	48
AR-AR	11	22
AR-DP	12	13
DP-DP	7	7
Totals	102	204

OV = Overflights, AR = Arrivals, DP = Departures

Table 2 Phase I Test Periods

Date	Local Time	Accepted Plans
9/08	12:00 - 14:00	10
	15:00 - 17:00	17
9/09	10:00 - 11:00	6
9/10	09:00 - 11:00	18
	15:00 - 17:00	36
9/11	09:00 - 10:00	15
Totals	10 hours	102

Phase I Experiment

During Phase I a single PGUI was operated on a desk-top workstation with a 20 in color monitor set up near the perimeter of Area 2. The objective was to obtain a quantitative comparison of conflict prediction and resolution with and without the aid of the CPTP tool. A test controller used the tool to identify potential conflicts and develop trial-plan trajectories for conflict resolution. A second test controller observed and recorded actual conflict resolution clearances given by the sector controller and any procedural factors affecting the conflict scenario. In some cases no clearances were issued because aircraft passed with greater than legal separation. During Phase I it was important that the tool-aided conflict resolution not influence the actual conflict resolution clearance, so the trial-plan resolution was not communicated to the sector controller. CPTP was configured to display conflicts for sectors 16, 17, and 28. Three test controllers participated in Phase I of the experiment. Figure 5 shows the test setup at the perimeter of Area 2.

Each time a test controller accepted a trial plan the current trajectory predictions for both conflict aircraft and the trial trajectory for the trial-planned aircraft were recorded to disk. Data recording was triggered by the accept button on the trial planning function. Host radar and flight plan messages for all aircraft were also recorded during each test period. The Phase I test periods and number of accepted trial plans are summarized in Table 2.

Fig. 5 CPTP tool at the perimeter of Area 2.

All accepted trial plans were analyzed to determine type of trial plan used by the test controllers for each conflict resolution. Information recorded by the second test controller and the radar tracks were analyzed to determine the actual resolution type used by the sector controller. Resolution types are categorized as follows:

DIRECT - fly direct to a future waypoint
VECTOR - heading change, then direct to waypoint
ALTITUDE - altitude change
SPEED - speed change
MULTIPLE - e.g., vector and altitude
NO RESOLUTION - no resolution by test controller
UNKNOWN - test or sector controller actions not clear
NO ACTION - no clearance given by sector controller.

In 12% of trial plan recordings analyzed for Phase I the predicted minimum separation between the accepted trial plan and the trajectory prediction for the other aircraft violated legal standards. Each instance is considered a no-resolution and could be either a tool usage error by the test controller, or an error in the minimum separation prediction and/or recording. The no-action cases correspond to instances when the sector controller let the aircraft pass with no action (recall that the probe horizontal separation criterion was 10 nmi). In 2% of the cases, actions of the sector controllers could not be determined from the data (unknown category).

Figures 6 and 7 show the resolution type percentages used by test controllers and sector controllers for the same set of conflict pairs. As shown in Fig. 6, test controllers using the CPTP tool chose a direct route to a future waypoint in 45% of conflicts analyzed. The on-duty sector controllers used a direct route to resolve only 11% of conflicts (Fig. 7). This indicates a

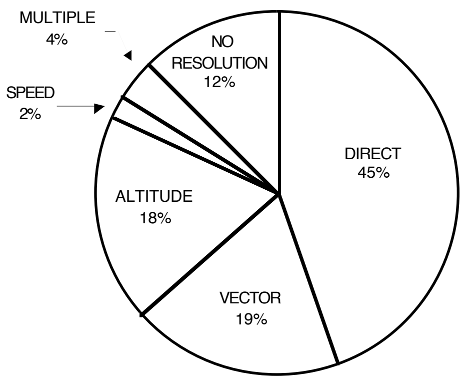

Fig. 6 Test controller resolutions (Phase I).

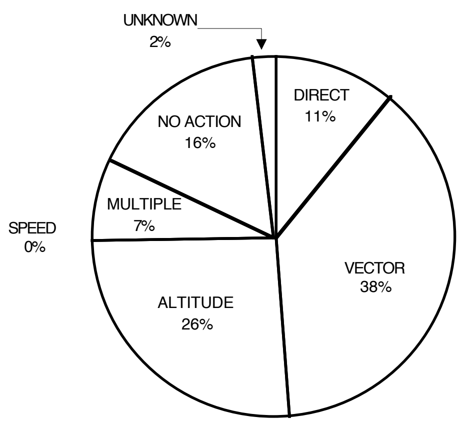

Fig. 7 Sector controller (baseline) resolutions (Phase I).

Table 3 Direct Resolutions (level-level) - Phase I

Conflict ac1 - ac2	ac1			ac2
	PF - TP		PF - TR	PF - TR
[a] denotes arrival	%	nmi	nmi	nmi
B737[a] - MD80	0.9	1.2	-0.2†	3.8†
B757 - LR25[a]	0.6	3.8	-1.2	-1.1
B757 - WW24[a]	8.1	56.9	44.1†	0.9†
B757 - B727	0.2	1.1	-0.3	-3.5
MD80 - LR25	6.9	21.5	3.3	-2.9
LR35[a] - MD80	0.6	0.8	-4.1†	-5.4†
B757 - EA32	0.1	0.5	-2.3	-1.7
MD11 - B737[a]	0.3	3.7	-1.1†	3.7†
D328[a] - B727	9.3	17.3	-8.6	-0.4
CL60 - C525	2.7	3.8	-0.6	-0.4
B767 - MD80	0.3	1.1	-11.3	-0.7
B737 - AC69	8.0	18.1	7.3	-3.4
DA20 - C550	0.7	6.3	-2.1	-0.9
B757 - B757	8.5	40.8	-4.1	-0.9
B757[a] - C500	7.1	8.6	6.4	-1.0
MD80 - B737[a]	0.4	2.7	-6.7	4.9†
B737[a] - EA30[a]	6.8	8.1	7.2	-0.3
B737[a] - B767[a]	13.4	15.7	9.5	-0.3
B757 - DA05	0.6	2.7	-2.7	-1.0
DC10 - B737	0.5	1.9	-4.5	-0.7
B757 - MD80	1.8	7.9	-3.1	-2.1
MD11 - EA32	0.3	2.2	-1.0	-0.6
B757 - L1011	6.0	57.1	41.7	-1.0
B737 - C650[a]	0.8	7.3	-0.7†	-9.2†
Average	3.5	12.1	1.4	-1.3

† distance not included in average

potential three-fold increase in direct route clearances with CPTP aiding. The "no-action" cases in Fig. 7 might be considered a rough false-alert measure. However, since the conflict criterion was set at 10 nmi the actual false-alert rate is likely lower than 16%. Legal horizontal separation is 5 nmi in enroute airspace, and some aircraft pass with separation greater than 5 nmi but less than 10 nmi without controller action. In Phase I, the time to go from current position to predicted first loss of separation at the time the trial plan was accepted by the test controller averaged 10.4 min, with a standard deviation of 4.4 min.

Test controllers nearly always chose a direct route to a future waypoint as a first trial planning option. A direct route often solved the conflict well before it became tactical and gave the aircraft a short cut. An added benefit for the controller is that a second clearance is not required, as it would be to clear the aircraft back on course following a heading vector. Even in cases where a conflict does not exist, if the aircraft gets a direct route clearance and no other conflicts are created, then the aircraft usually benefits by a shorter route and the controller benefits by having one less potential conflict to watch. An exception may be the case where a shorter route is a less optimal wind route.

To illustrate the potential savings with direct routes to future waypoints, those Phase I conflicts resolved by direct-route trial plans were analyzed to compare horizontal path distances. The results for pairs that were level - level at predicted first loss of separation are shown in Table 3. In each case, the test controller has created and accepted a trial plan for the first aircraft (ac1) in the conflict pair. Here distances along the trial-plan route (TP) and the actual aircraft radar track (TR) are compared to the original CTAS route profile (PF) for ac1; the TR and PF routes for ac2 are also compared. Each path was measured from the point at which the trial plan was accepted to the capture waypoint; all paths were in the range 100–350 nmi in length.

The (PF–TP) column for ac1 shows the potential savings which averages 12.1 nmi (3.5%) per direct route. The (PF–TR) column shows the actual savings, averaging 1.4 nmi, not including five cases in which clearances were given to ac2 instead of ac1. (In ten cases no clearance was given to either aircraft.) Since no communication existed between the test and sector controllers in Phase I, the difference between the potential savings (PF-TP) and actual savings (PF-TR) is a measure of benefit with CPTP aiding. The average difference between potential savings and actual savings is seen to be 10.7 nmi.

The (PF–TR) column for ac2 was included in Table 3 to provide a “benchmark” for how close an aircraft can follow a specific route. The untagged distances are for those cases in which the intent to “follow” the PF route was clear. Note that in each of these the track is longer than its predicted route: navigation, and radar errors have probably contributed most to the difference, which averages –1.3 nmi. Five of the six tagged elements in the column (not included in the average) represent those conflicts resolved with clearances to ac2 – the positive values are for “directs”; the negative are for “vectors”. In the sixth, ac2 deviated from the predicted route prior to its waypoint.

An estimate of cost savings to an airline as a function of path length saved is expressed as:

$$CS = (C/V)\Delta S \qquad (1)$$

where CS is the cost saved in \$, C is the airline Direct Operating Cost in \$/hr, V is ground speed in kt, and ΔS is path savings in nmi. A value for C of \$1,493/hr, which is representative of the airborne operating cost (fuel and oil, crew, maintenance) for a B757 aircraft[13], and a nominal speed of 420 kt were used to calculate the potential cost savings for the conflicts analyzed in Table 3. The estimated savings are shown in Table 4. Note that these potential savings are only for aircraft that were predicted in conflict during the 10-hr test period in sectors 16, 17, and 28. The direct-route resolutions yield a potential benefit for the airlines of \$43 per conflict. There is potential for far greater savings if direct routes for all aircraft could be trial planned, not just those aircraft predicted in conflict.

Table 4 Estimate of airline cost savings for direct route resolutions in Phase I

Average Savings	ΔS (nmi)	CS (\$)
Potential	12.1	43.01
Actual	1.4	5.05

Phase II Experiment

During Phase II, three CPTP systems were operated on notebook workstations with 12 in color monitors set up next to the D-Side controller position at sectors 16, 17, and 28. Prior to each test period the sector filters on the three CPTP tools were configured to show conflicts predicted to occur inside the test sector as well as conflicts predicted to occur outside the test sector which involved at least one aircraft currently inside the test sector. Following the initial set up, test controllers were free to adjust the sector filter as desired and they typically adjusted their sector filters to display conflicts in multiple sectors. Sector 16 usually displayed conflicts for sectors 8, 9 and 16; Sector 28 usually displayed conflicts for sectors 28, 29 and 30. Controllers typically elected not to display conflicts between two Denver arrivals going to the same meter fix. Arrivals to the same fix are tightly controlled by the arrival controller - display of these conflict was deemed unnecessary. Fifteen test controllers participated in the Phase II evaluation. Figure 8 shows the test setup at sectors 16 and 17.

Test controllers, one at each position, monitored the conflict prediction display and created conflict resolution trajectories using the trial planner. Test controllers then verbally suggested the CPTP-based clearances to the sector controller. Test controllers were instructed to accept only those trial plans that were to be issued by the sector controller as clearances. As in Phase I, when the test controller hit the accept button, the trajectory predictions for both aircraft and the trial trajectory were recorded to disk. If for any reason the sector controller decided not to implement the trial plan as presented, the test controller was instructed to reject and/or modify the trial plan. The Phase II test periods and number of accepted trial plans are listed in Table 5.

Fig. 8 CPTP tool at Sectors 16 and 17.

In post-test analysis of the trial plan trajectories and Host track records, there appear to be significant differences in some cases between the accepted trial plans and actual clearances. The accepted trial plans were analyzed and categorized according to the action of the sector controller relative to the test controller's suggested clearance. Accepted trial plans were categorized as follows:

FOLLOWED - test controller recommendation followed
NOT FOLLOWED - recommendation not followed
AMBIGUOUS - not clear if recommendation followed.

Of the 181 conflicts analyzed 132 (73%) were followed, 46 (25%) were not followed, and 3 were ambiguous. 23 cases were not included in the analysis because they were inadvertently accepted by the test controller. It should be noted that the percentage of no-resolution cases accepted by the test controller dropped significantly (to 6%) during Phase II. This indicates that the test controllers were more familiar with the operation of the tool during the second and third weeks of testing. The 132 CPTP-based trial plan resolutions that were followed, i.e., issued to aircraft as clearances, have been categorized by resolution type as was done for the Phase I data. The results are shown in Fig. 9.

The results show more than a two-fold increase in the number of direct route clearances with the CPTP tool in

Table 5 Phase II Test Periods

Date	Local Time	Accepted Plans
9/15	09:30-10:30	0
	15:00-17:00	18
9/16	12:00-14:00	3
	15:00-17:00	11
9/17	09:00-11:00	9
	15:00-16:30	16
9/18	09:00-10:30	6
	15:00-17:00	19
9/19	09:00-10:30	14
	15:00-17:00	9
9/22	09:30-10:30	3
	15:00-16:00	7
9/23	09:00-11:00	17
	15:00-17:00	15
9/24	09:00-10:00	5
	15:00-17:00	21
9/25	08:30-09:45	13
	15:00-17:00	18
Totals	88.5 sector-hours	204

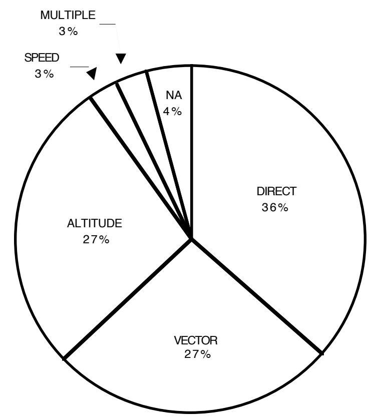

Fig. 9 Sector controller (CPTP) resolutions (Phase II).

use. Of the 132 CPTP-based clearances issued to aircraft, 47 (36%) were direct to a future waypoint, compared to 11% from Phase I data (Fig. 7) without CPTP-aiding. For the Phase II data, the average time-to-go from current position to predicted first loss of separation at the time the trial plan resolution was accepted was 7.4 min; the standard deviation was 4.2 min. The shorter average time-to-go compared to that of Phase I (10.4 min) might be attributed to procedural factors for issuing clearances.

The large increase in direct route clearances with CPTP in use is attributed to several factors. The conflict probe gives the controller a longer lead-time prediction, and a tool-based confirmation that a conflict might occur without corrective action. The trial planner allows the controller to quickly check and confirm that a direct route is conflict free. The waypoint menu in the trial planner, which includes outside-Center waypoints, displays all downstream waypoints in the route of flight, so that a controller does not have to spend additional time checking the route to determine a workable downstream waypoint. Under current operations a controller might vector an aircraft for conflict resolution, determine a downstream waypoint, and then clear the aircraft to that waypoint.

To illustrate the actual savings with direct routes to future waypoints, Phase II conflicts resolved by direct trial plans (and issued as clearances) were analyzed to again compare horizontal path distances. The results for pairs that were level – level at first loss of separation are shown in Table 6. Here the test controller has created a trial plan for the first aircraft (ac1) in each conflict pair. In each case, a clearance was issued to ac1 to "follow" the trial plan. Again, distances compared are the CTAS-predicted route (PF), the aircraft radar

Table 6 Direct Resolutions (level-level) - Phase II

Conflict	ac1			ac2
ac1 - ac2	PF - TP		PF - TR	PF - TR
[a] denotes arrival	%	nmi	nmi	nmi
MD80 - B727	0.9	8.1	5.0	-0.9
B757 - B737	0.6	3.5	1.5	-1.5
B727 - MD80	1.0	4.4	1.2	-2.8
B727 - B727	0.7	5.5	5.0	-0.6
DC8S - DC10	1.0	8.6	8.3	-0.5
MD80 - B727	1.4	6.6	3.7	-9.5†
B727[a] - B727	4.8	11.0	11.6	-3.3
B737[a] - B747	8.7	9.9	9.5	-0.6
L1011 - B757	0.1	0.3	-0.9	-2.0
EA32 - L1011	0.9	7.5	6.7	-1.4
B727 - DC10	0.4	2.0	1.7	0.1
MD90 - B757	0.2	0.7	-7.0	-0.5
MD88[a] - B727	2.1	1.7	1.5	-0.5
B757 - B767	0.1	5.2	-0.3	-2.6
B757 - B757	1.3	6.6	6.4	-0.2
B757 - B767	0.3	2.5	-0.1	-2.3
B757 - MD80	0.3	0.9	-1.3	-2.8
B737 - B757	3.0	16.6	16.2	-0.4
B737 - B727	0.9	3.8	3.4	-5.4
B757 - B737	1.4	7.7	-2.3	-0.4
MD80 - B737	2.7	15.0	0.8	-1.5
Average	1.5	6.1	3.4	-1.5

† distance not included in average

track (TR), and the trial-plan route (TP), and each path was measured from the point at which the trial plan was accepted to the capture waypoint.

A first observation is that the average maximum potential path saving for the entries in the (PF–TP) column for ac1 (6.1 nmi) is only about half that achieved by the direct trial-plan resolutions of Phase I (12.1 nmi, Table 2), possibly because in Phase II the test controller was constrained by “real-world” conditions, as well as the need to have each trial plan accepted by the sector controller. A second observation is that even though ac1 was following the trial plan, the (PF–TR) column indicates that on average, only about 55% of the predicted saving (3.4 nmi) was actually realized. Part of the difference can be attributed to navigation and track errors. In three of the cases, however, ac1 deviated from the trial-plan route before reaching the capture waypoint, perhaps to avoid another conflict or bad weather, and these lowered the average path saving. A third observation is that while six arrival aircraft were given “directs” in Table 3 (Phase I), only three arrivals appear in Table 6. This suggests that when the sector controller considers arrival conflicts, other resolutions (altitude, speed) may take precedence. The estimated savings are given in Table 7.

The (PF–TR) column for ac2 was again included in Table 6 to augment the benchmark for route following. The untagged distances are for those cases in which the intent to “follow” the PF route was clear. Note that in each of these the track is again longer than its predicted route: navigation and radar errors have probably contributed most significantly to the difference, which averages –1.5 nmi. Since all clearances were issued to ac1, there is only one tagged element in the column (not included in the average). In this case, ac2 deviated from the predicted route prior to its given waypoint.

Observations and Controller Comments

The interaction of test and sector controllers (during Phase II) appeared to be very good. In many instances a sector controller would ask the test controller to check the conflict status on a particular aircraft pair. A typical exchange might be: *Sector controller*: “What do you have on United and Delta?” *Test controller*: “You’ve got 7 (nmi)”. In this example the sector controller, watching a potential conflict situation, wanted to know the tool’s prediction of minimum separation. In some instances a sector controller asked the test controller to work a resolution on a particular conflict pair. In others the sector controller leaned over to take a look at a particular conflict pair on the CPTP display.

The CPTP tool’s ability to confirm that a trial plan resolves the conflict *and* does not create any other conflicts was consistently identified by the test controllers as one of the tool’s most powerful features. The Denver Center Air Traffic Manager said: “That (capability) I would like to have out here right now.” Another useful feature was encapsulated by the controller comment: "Showing me the destination airport in the flight data block gives me a pretty good idea of the aircraft's route of flight."

During one test period Sector 9 was very busy with five aircraft over the number that activates the monitor alert. One of the test team controllers was on duty at the R-Side position. The test controller running the CPTP tool was developing conflict resolutions for Sector 9.

Table 7 Estimate of airline cost savings for direct route resolutions in Phase II.

Average Savings	ΔS (nmi)	CS ($)
Potential	6.1	21.70
Actual	3.4	12.10

During the debrief session the sector controller said: "We were down the tubes (very busy). Billy (test controller) walked up and told me every option I had. I was able to discard a lot of options I was thinking of. It's just more assurance of what's going on."

Test controllers consistently identified the tool's strategic (10-20 minute time horizon) prediction and resolution capability as highly beneficial. Many conflicts were predicted well across sector boundaries. The tool was found to be especially beneficial in cases where two aircraft were coming together near a sector boundary where the sector controllers may not have seen them until the conflict became tactical, i.e., less than 5 min to go.

It was noted early in the field test that an operational CPTP capability should include a weather display showing thunderstorms and the altitudes of their tops, so that controllers can trial plan accordingly. Providing this capability is now under consideration.

Operational Concerns

CTAS trajectory predictions include a top-of-climb prediction based on its cleared altitude, assumed aircraft weight, and aircraft performance characteristics. The predicted top-of-climb point is displayed when a conflict is selected and may be optionally displayed for any climbing aircraft. The test controllers noted that climb predictions for some aircraft were way off. In some cases the problem caused missed conflicts and in others, false conflicts. The problem was due to inaccurate modeling of the climb performance of some aircraft (e.g., B757). The aircraft models have since been corrected and climb predictions have improved.

The conflict prediction algorithm allows vertical separation criteria to be adjusted depending on the conflict type: 1) both aircraft level, 2) one aircraft changing altitude, 3) both aircraft changing altitude. This accounts for the additional uncertainty in prediction of non-level trajectory segments. Test controllers thought it would be useful to use a higher separation criterion for conflicts involving aircraft climbing towards overflying aircraft in level flight, especially in cases where the aircraft are flying head-on horizontally. A 3000 ft. vertical separation criterion was selected during one of the Phase II test periods. It was immediately noted, however, that in order to prevent nuisance conflicts of type 2 and 3, the conflict search must distinguish between cases where vertical separation is decreasing and those where separation is increasing. Consider an arrival aircraft level at FL330 with a top-of-descent point within 10 miles (horizontally) of an overflight level at FL350. In this case separation is increasing and therefore should not be displayed as a conflict. The conflict prediction logic is now improved to more accurately predict transition airspace conflicts involving climbing and descending aircraft using increased vertical separation criteria.

A time delay of up to 2 min on the CPTP track display occurred during high traffic periods when the track count rose above about 320 aircraft. This delay was due to limited capacity of the 9600 baud serial connection from the Host. This limited some testing during the 10:00 to 11:00 am local time period. The new Host Interface Device (HID) recently installed at Denver Center and scheduled for installation at other facilities should eliminate this problem.

Concluding Remarks

CTAS Conflict Prediction and Trial Planning (CPTP) capability was tested for 98 sector-hours over a 13 day period in 3 high altitude sectors on the operational floor at Denver Center. 132 CPTP-aided clearances were issued to aircraft during the test period. 15 full performance level controllers participated in the test. Many conflicts were resolved by sending one aircraft direct to a downstream fix (45% in Phase 1 and 36% in Phase 2).

Comparison of baseline (no aiding) clearances with CPTP-aided clearances actually issued show more than a two-fold increase in direct route resolutions. The increase is attributed to the relative ease with which a direct route resolution could be trial planned and confirmed conflict free. Using CPTP, two mouse clicks on the flight data block provides rapid (~2 sec) feedback on the conflict status of a direct route.

An analysis of baseline and CPTP-aided cruise/cruise conflict resolution clearances showed an average *potential* savings of 12.1 mi and $43 in operating cost for the aircraft given the direct route clearance. The actual savings for aircraft given CPTP-aided direct-route clearances during the test are estimated to be 3.4 nmi and $12 per aircraft.

Test controllers consistently identified CPTP's most powerful feature was its ability to confirm that a trial plan resolves the conflict *and* does not create any other conflicts. Any conflict prediction and resolution tool should allow the controller to quickly and easily check a trial plan and confirm that the trajectory is conflict free.

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